User manual CO$_2$-tool for electricity, gas and heat from biomass

>> Focus on energy and climate change

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This document gives practical instructions on how to use the CO2 tool. Background information on the methodology and data sources used in the CO2 tool can be found in the methodology document that accompanies this tool.

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1 Introduction

1.1 Background

Biomass can be converted into final energy in the form of electricity, heat or biofuels. This final energy is considered 'green' since it does not result in the release of CO_2 with 'fossil carbon'. However, several steps in producing this final energy from biomass do generate fossil carbon emission. Examples are: Cultivation and harvesting, transport, drying, size reductions, etc. The reduction in greenhouse gas (GHG) emission compared to final energy from a fossil fuel is therefore less than 100%. How much less than 100% depends on the type of biomass, the transport distance and method and the processing steps. The diversity in biomass, conversion technologies, ways of transport and the geographical spread of both biomass sources and the energy demand result in numerous possible biomass-to-energy chains. Each of these chains have a different GHG emission performance. The calculation of the total GHG-emission from a specific chain is time-consuming. The CO2-tool is software to make these calculations easier.

1.2 How to use the tool and this manual

The tool has a number of pre-defined biomass-to-energy chains; each chain on a separate sheet. All those sheets are accessible from the sheet 'Directory'. The sheet 'Standard values' contains pre-defined emission factors. This sheet cannot be modified. The sheet 'About' contains some general information.

In all sheets, the background colour of the cells denotes the type of cell:

Main title

Sub title

Category

Calculated value or unit / general background colour

User input

Total

Chapter 2 of this manual describes all items present on the sheets.

2 Composition of the spreadsheets

2.1 Methodology

According to the Annex I of the "Report from the commission to the Council and the European Parliament on sustainability requirements for the use of solid and gaseous biomass resources in electricity, heating and cooling", the greenhouse gas emission from the production of solid and gaseous biomass fuels should be calculated by counting the emissions from separate processes in the biomass pathway, i.e. cultivation, transport and processing. The possible biomass-to-energy pathways so far applicable are shown in Figure 2 - 1. For each of these boxes, the GHG emissions will be calculated separately.
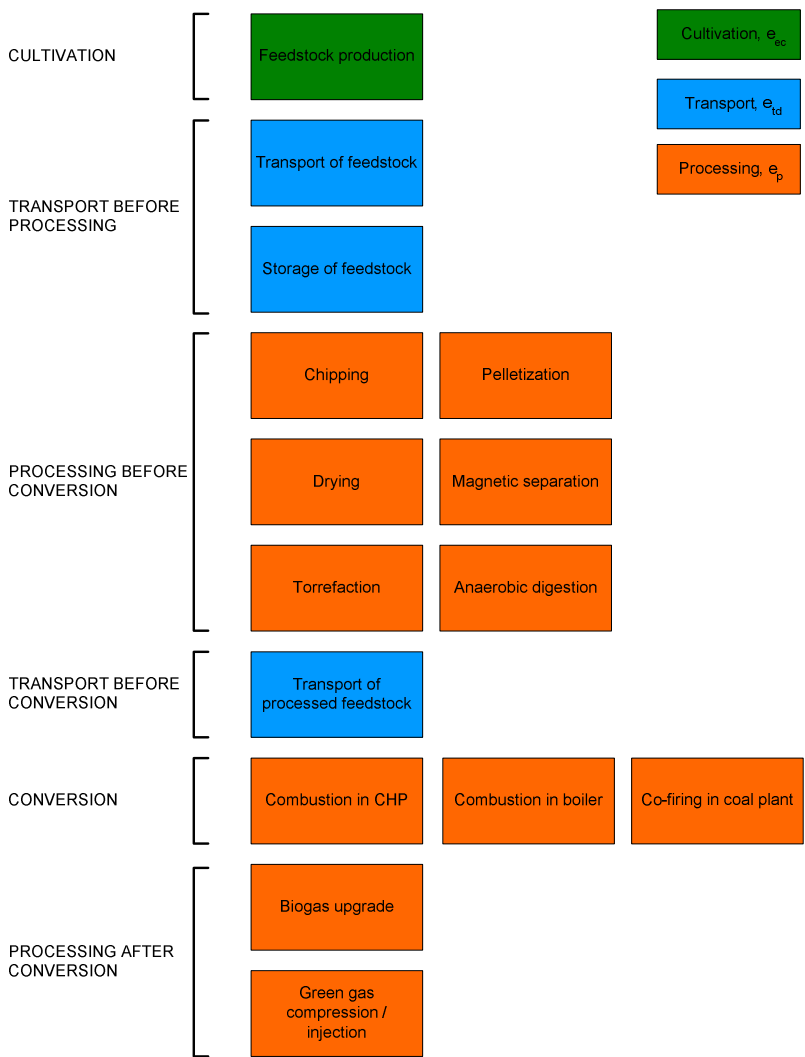
Figure 2 - 1   Possible processes for different biomass-to-energy pathways

2.2 General overview

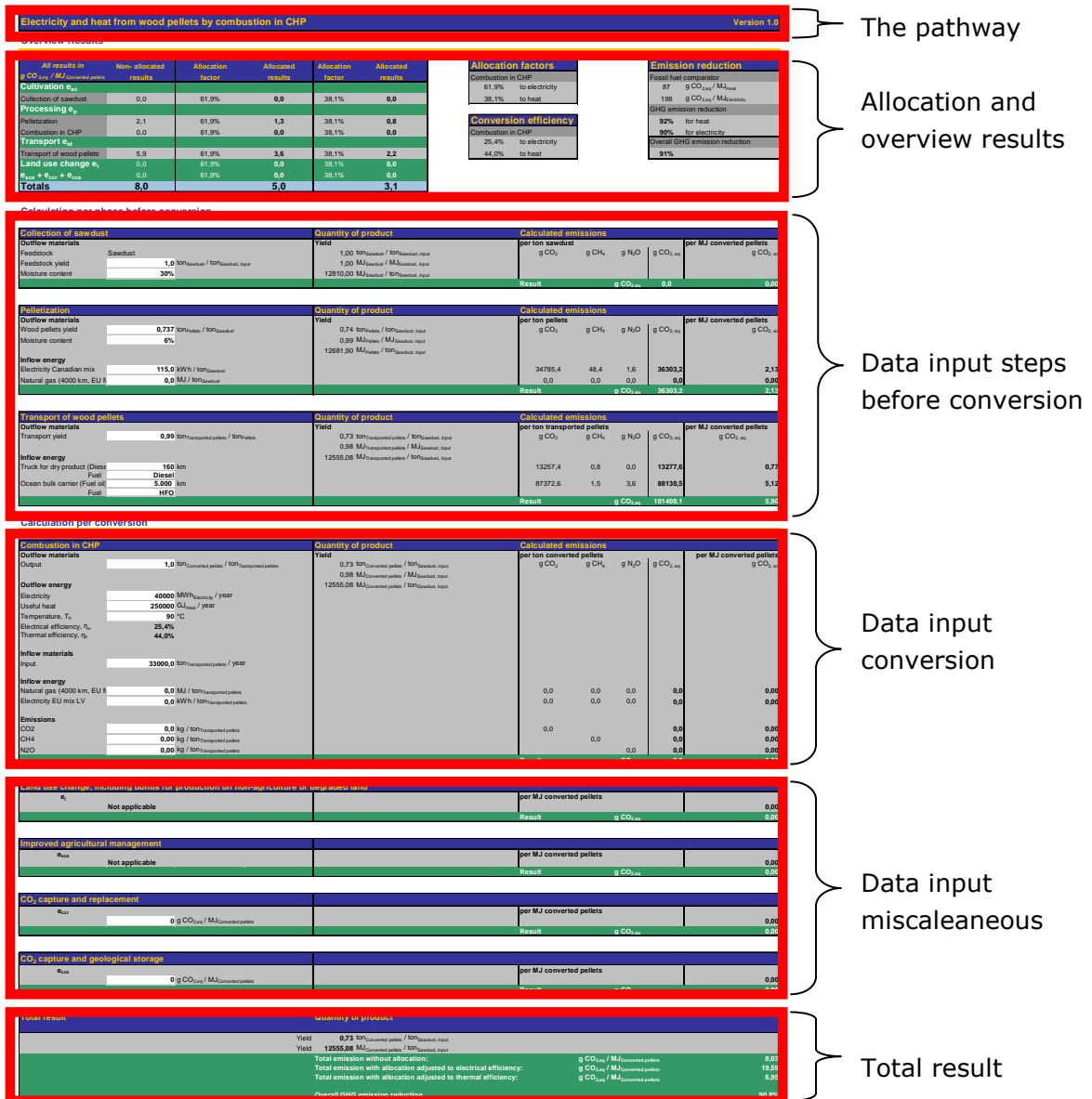The general structure of the calculation format is explained in Figure 2 - 2.

The pathway

Allocation and overview results

Data input steps before conversion

Data input conversion

Data input miscaleaneous

Total result

Figure 2 - 2   General structure of the format

3 The data entry boxes

3.1 Overview results

According to the '*Report from the commission to the council and the European Parliament on sustainability requirements for use of solid and gaseous biomass sources in electricity, heating and cooling*' (hereafter referred to as: The EC communication), the total greenhouse gas emissions or emission savings from the production of solid and gaseous biomass fuels are divided into 8 different categories. The emissions are attributed to cultivation, processing, transport and land use change (2x) while the emission savings are ascribed to carbon capture issues (3x). For this reason, the result of the emission calculations are categorized into these 5 main aspects which are shown in the box named "overview of results", shown in Figure 3 - 1.

All results in $g\ CO_{2,eq}\ /\ MJ_{Converted\ pellets}$	Non- allocated results	Product electricity		Product heat	
		Allocation factor	Allocated results	Allocation factor	Allocated results
Cultivation e_{ec}					
Collection of sawdust	0,0	61,9%	**0,0**	38,1%	**0,0**
Processing e_p					
Pelletization	2,1	61,9%	**1,3**	38,1%	**0,8**
Combustion in CHP	0,0	61,9%	**0,0**	38,1%	**0,0**
Transport e_{td}					
Transport of wood pellets	5,9	61,9%	**3,6**	38,1%	**2,2**
Land use change e_l	0,0	61,9%	**0,0**	38,1%	**0,0**
$e_{sca} + e_{ccr} + e_{ccs}$	0,0	61,9%	**0,0**	38,1%	**0,0**
Totals	**8,0**		**5,0**		**3,1**

Figure 3 - 1   Overview results

This box gives an overview of both allocated and non-allocated emissions over the main product per process including conversion and the total emissions. The allocated results are based on the allocation factor which is presented in the middle column and the efficiency of the main product in the conversion process if applicable. The allocation factors for the processes with no emissions are kept at zero.

The emissions during the combustion of solid and gaseous biomass are considered to have a zero greenhouse gas emissions in accordance with the calculation methodology as described in Annex I of the EC Communication. This is also the case for the collection of waste feedstock. Wastes and residues shall be considered to have a zero life-cycle greenhouse gas emissions up to the process of collection of those materials.

Note that the effect of indirect land use changes (ILUC) is not included since this item is still under discussion in the EC.

3.2 Allocation factors and conversion efficiencies

Where a fuel production process produces, in combination, the energy carrier for which emissions are being calculated and one or more other co-products, green house gas emissions shall be distributed among the energy carrier (main product) and the co-products in proportion to their energy content. For accounting of useful heat as co-product, the allocation between the useful heat and other co-products shall be made using the Carnot efficiency (C). The allocation factor as shown in Figure 3 - 2 is calculated according to the electrical and thermal efficiencies and the absolute temperature of the useful heat at point of delivery. For details about this calculation the user is directed to the accompanying methodology document.

Allocation factors	
Combustion in CHP	
79.1%	to electricity
20.9%	to heat

Figure 3 - 2   Allocation factors

The box for the allocation factors shows the allocation over different commodities, i.e. electricity, heat and green gas. In case of a combustion process, there are three possible combinations of biomass conversion into electricity and/or heat:
- Production of heat in a boiler;
- Production of electricity as main product and heat as co-product in a CHP;
- Production of electricity in a coal plant.

The data boxes for these conversion boxes are described in section 3.5.5. In case of the production of electricity and/or heat, the electrical and thermal efficiencies will be presented in the box as shown in Figure 3 - 3.

Conversion efficiency	
Combustion in CHP	
26.8%	to electricity
20.0%	to heat

Figure 3 - 3   Conversion efficiencies

3.3 Emission reduction

For electricity and heat production, the fossil fuel comparator will be respectively 198 ($EC_{F(el)}$) and 87 ($EC_{F(h)}$) gCO_{2eq} per MJ commodity. Greenhouse gas emission savings from electricity and heat is then calculated according to the calculation methodology as reported in the aforementioned Annex I. The fossil fuel comparator for green gas is assumed to be equal to the emissions for Natural gas (4000 km, EU Mix quality) as defined in BioGrace, which is 67.59 gCO_{2eq} per MJ. For the biofuel pathways, the reference value will be 85 gCO_{2eq} per MJ as laid down in RED Annex V c. The box for

the emission reduction calculations for electricity and/or heat and green gas is shown in Figure 3 - 4. Depending on the main commodity, the emission reduction will be calculated with the corresponding fossil fuel comparator.

Emission reduction		
Fossil fuel comparator		
87	g $CO_{2,eq}$ / MJ_{Heat}	
198	g $CO_{2,eq}$ / $MJ_{Electricity}$	
GHG emission reduction		
90%	for heat	
88%	for electricity	
Overall GHG emission reduction		
89%		

Emission reduction	
Fossil fuel comparator	
67.96	g $CO_{2,eq}$ / $MJ_{Injected\ green\ gas}$
GHG emission reduction	
13%	for green gas
Overall GHG emission reduction	
13%	

Emission reduction	
Fossil fuel comparator (diesel)	
85.0	g $CO_{2,eq}$/MJ_{Fuel}
GHG emission reduction	
66%	for rapeseed oil
Overall GHG emission reduction	
66%	

Figure 3 - 4   Calculation of the emission reductions for electricity/heat (left), green gas (middle), liquid biofuels (right)

The emission reduction boxes consist of the following values:
- Corresponding fossil fuel comparators;
- Calculated GHG emission reduction; based on the total emissions E, the conversion efficiencies and the fossil comparator;
- Calculated overall GHG emission reduction; based on the calculated GHG emission reduction and the allocation factors.

3.4 Calculated emissions

The emissions per process are calculated through the corresponding emission factors in the "standard values" sheet. The calculated greenhouse gas emissions per process are presented in the two boxes shown in Figure 3 - 5. The left box consists of 3 column ranges from which the left column range contains the emissions expressed in grams greenhouse gas (gCO_2, gCH_4, gN_2O) per ton feedstock. The middle column displays the emissions expressed in grams CO_2 equivalent ($gCO_{2,\ eq}$) per ton feedstock and the right column shows the emissions expressed per MJ main product, i.e. electricity and/or heat for combustion chains and green gas for digestion chains. The right box shows the emissions per MJ by-product, which is the produced useful heat in case of a CHP.

Calculated emissions				
per ton pellets				per MJ converted pellets
g CO_2	g CH_4	g N_2O	g $CO_{2,\ eq}$	g $CO_{2,\ eq}$
34785.4	48.4	1.6	36303.2	2.13
0.0	0.0	0.0	0.0	0.00
Result		g $CO_{2,eq}$	36303.2	2.13

Figure 3 - 5   Calculated emissions per ton feedstock and per MJ commodities

The total emissions per process, both per ton feedstock as per MJ commodity, are given in the green row at the bottom of this box.

3.5 Data input for calculation

In order to calculate the greenhouse gas emissions for a specific pathway, all relevant data should be entered for each process in the pathway. The relevant data for the calculation of the emissions can be specified in the corresponding boxes for a certain process. These boxes consist of two columns. The left column includes all the input fields for the data which are divided into 5 categories, which are:

1   Outflow materials; includes product yields and moisture contents if relevant;
2   Inflow materials; includes material input such as fertilizers, pesticides and seeds, especially for cultivation process;
3   Inflow energy; includes energy (electricity/natural gas) input for a certain process;
4   Outflow energy; includes the yield of energy (electricity/heat) of a certain conversion process and also energy efficiencies and temperature of produced heat
5   (Field) emissions; includes direct GHG emissions during a certain process.

The right column shows the calculation of the quantity of the outflow product per process with relation to the input material. The quantities are expressed in both energy contents as well as weight contents. The next expressions are used for the calculation of the quantities:

6   ton output material / ton input material;
7   MJ output material / MJ input material;
8   MJ output material / ton input material.

In case the pathway includes a cultivation process, the input material will be the amount of land in hectares that is used for cultivating.

3.5.1 Cultivation

In case the feedstock is not a waste, e.g. energy crops, the emission from the cultivation and harvesting of raw materials should be included in the calculation. Emissions from inflow materials per hectare, i.e. the use of fertilizers, pesticides, seeds and the emission from inflow energy per hectare, i.e. fuel and electricity, should be specified in this box, as shown in figure Figure 3 - 6. In addition, the field emission due to soil management and fertilization should also be filled in this box.

Figure 3 - 6   Input field for cultivation

The user should also enter the data on outflow materials. The yield of raw material per hectare and the moisture content of the cultivated raw material should be specified in this box as well.

3.5.2 Transport before processing

Emissions from transport includes the emissions from transport and storage of raw materials (feedstock). The data box for transport of feedstock is shown in Figure 3 - 7.

Figure 3 - 7   Input field for transport before processing

This box includes 3 input fields which should be filled in by the user. The transport yield covers possible material or weight losses during transportation. For straightforward transportations over short distances, the material losses could be neglected. In this case, the transport yield field should contain a 1.

The transport of the feedstock can be by truck on diesel or ocean bulk carrier on HFO. This box can easily be expanded by a possible transport through an inland barge. The user should specify the relevant transport distances in kilometers and the fuel type in the corresponding cells. The "standard values" implemented in the tool contain data on different fuel types which can be selected. These fuel types are:

- Diesel

- Gasoline
- HFO
- HFO for maritime transport
- Ethanol, methanol
- FAME
- Syn diesel (BtL)
- HVO

The entry field for fuel type is a text string. Therefore, the user should type in the appropriate fuel type exactly as it is written in this list. If a type of transport occurs in different phases, then the total distance per transport type can be filled in.

The data box for storage of transported feedstock is shown in Figure 3 - 8.

Handling & storage of maize		Quantity of product	
Outflow materials		Yield	
maize yield	1.0 ton stored maize / ton transported maize	3.88 ton stored maize / ha	
		1.00 MJ stored maize / MJ maize input	
Inflow energy		61064.89 MJ stored maize / ha	
Electricity EU mix LV	0.0 kWh / ton transported maize		
Emissions			
CO2	0.0 kg / ton transported maize		
CH4	3.1 kg / ton transported maize		
N2O	0.014 kg / ton transported maize		

Figure 3 - 8   Input field for storage

In the first input field, the user should fill the material yield for storage. If the losses are neglected, the yield field should contain a 1. If electricity is used for handling the materials during the storage, this should also be specified in the corresponding cell. Greenhouse gas emissions from the emissions during the storage of feedstock should be specified in kg per ton feedstock in the corresponding cells.

3.5.3 Processing before conversion

According to the calculation methodology, the emissions from feedstock processing shall include the emissions from the use of materials and energy, i.e. electricity and natural gas. The possible processing steps before the conversion to final commodity, i.e. electricity, heat and green gas, are presented in this section.

The pathways that are predefined in this CO_2-tool include 6 processes through which the feedstock is processed before conversion to the final commodity. These processes are:
- Pelletization
- Chipping
- Drying
- Torrefaction
- Magnetic separation
- Anaerobic digestion

The input boxes for pelletization, chipping and drying are given in Figure 3 - 9, Figure 3 - 10 and Figure 3 - 11 respectively. The material yields for these processes are calculated based on the change in moisture content. However, the user can also fill in the yield manually. The amount of electricity in kWh per ton input material and natural gas in MJ per ton input material that is required for the relevant feedstock processes should be entered as well.

Pelletization		Quantity of product
Outflow materials		Yield
Wood pellets yield	0.632 ton$_{Pellets}$ / ton$_{Sawdust}$	0.63 ton$_{Pellets}$ / ton$_{Sawdust,\ input}$
Moisture content	6%	0.99 MJ$_{Pellets}$ / MJ$_{Sawdust,\ input}$
		10870.20 MJ$_{Pellets}$ / ton$_{Sawdust,\ input}$
Inflow energy		
Electricity Canadian mix	115.0 kWh / ton$_{Sawdust}$	
Natural gas (4000 km, EU M	0.0 MJ / ton$_{Sawdust}$	

Figure 3 - 9   Input field for processing before conversion (pelletization)

Chipping		Quantity of product
Outflow materials		Yield
Wood chips yield	0.707 ton$_{Chips}$ / ton$_{Wood\ waste}$	0.71 ton$_{Chips}$ / ton$_{Wood\ waste,\ input}$
Moisture content	30%	0.99 MJ$_{Chips}$ / MJ$_{Wood\ waste,\ input}$
		9058.50 MJ$_{Chips}$ / ton$_{Wood\ waste,\ input}$
Inflow energy		
Electricity Canadian mix	75.0 kWh / ton$_{Wood\ waste}$	

Figure 3 - 10   Input field for processing before conversion (chipping)

Drying		Quantity of product
Outflow materials		Yield
Dry chips yield	0.661 ton$_{Dry\ chips}$ / ton$_{Chips}$	0.468 ton$_{Dry\ chips}$ / ton$_{Wood\ waste,\ input}$
Moisture content	10%	0.842 MJ$_{Dry\ chips}$ / MJ$_{Wood\ waste,\ input}$
		7699.73 MJ$_{Dry\ chips}$ / ton$_{Wood\ waste,\ input}$
Inflow energy		
Natural gas (4000 km, EU	0.0 MJ / ton$_{Chips}$	

Figure 3 - 11   Input field for processing before conversion (drying)

Note that in case of wood waste or sawdust as input feedstock, all the processes take place in Canada. Therefore, the emissions from electricity use are based on the Canadian electricity fuel mix. In case the processes take place elsewhere, the electricity emission data should be added in the "stand values" sheet and typed in the input box manually in the corresponding cell. The EU mix data are already included in the "standard values" sheet under the name "Electricity EU mix LV" and "Electricity EU mix MV".

For the torrefaction and magnetic separation processes, the material yields should be specified in the corresponding cells. The input boxes of these processes are shown in Figure 3 - 12 and Figure 3 - 13 respectively.

Torrefaction		Quantity of product
Outflow materials		**Yield**
Torrefied chips yield	0.700 ton torrefied chips / ton dry chips	0.38 ton torrefied chips / ton wood waste input
Moisture content	3%	0.739 MJ torrefied chips / MJ wood waste input
		6761.81 MJ torrefied chips / ton wood waste input
Inflow energy		
Electricity Canadian mix	92.0 kWh / ton dry chips	
Emissions		
CH4	0.00 kg / ton dry chips	

Figure 3 - 12   Input field for processing before conversion (torrefaction)

Magnetic separation		Quantity of product
Outflow materials		**Yield**
Chips yield	0.99 ton chips / ton demolition wood	0.99 ton chips / ton demolition wood input
		0.99 MJ chips / MJ demolition wood input
Inflow energy		
Electricity EU mix LV	0.6 kWh / ton demolition wood	

Figure 3 - 13   Input field for processing before conversion (magnetic separation)

For these processes, the user should enter the material weight yield for the process manually. For torrefaction, the yield value is based on the change in moisture content before and after the torrefaction process but also on certain amount of material loss due to the partial gasification of the material into torrefaction gas that eventually is combusted. The moisture content of the feedstock during the magnetic separation will not change. Therefore, no input field is included for moisture content.

Torrefaction is assumed to be taking place in Canada. So, the "Electricity Canadian mix" option is used here. The magnetic separation occurs in the Netherlands for which "Electricity EU mix LV" is used.

The data required for the calculation of emissions for anaerobic digestion can be specified in the box shown in Figure 3 - 14. The biogas production is calculated for the separate digestion of a feedstock (mono-digestion).

Anaerobic digestion		Quantity of product
Outflow materials		**Yield**
Biogas yield	21.0 m3 biogas / ton stored manure	21.00 m3 biogas / ton manure input
Methane content	55%	0.51 MJ biogas / MJ manure input
		410.03 MJ biogas / ton manure input
Inflow energy		
Natural gas (4000 km, EU)	14.07 MJ / ton stored manure	
Electricity EU mix LV	3.78 kWh / ton stored manure	
Emissions		
CH4	0.082 kg / ton stored manure	

Figure 3 - 14   Input field for processing before conversion (anaerobic digestion)

The biogas yield in m^3 biogas per ton input and the methane content of biogas should be entered in the first two cells. Another important parameter is the amount of heat that is required to warm up the digester and to maintain the temperature inside the

digester. The required heat and electricity for the digester should be specified in MJ per ton input and kWh per ton input respectively.

During the digestion process, certain amount of methane will leak from the digester. The emissions due to methane leakage in kg per ton input should be entered in the corresponding cell.

In practice, often co-digestion of combinations of substrates is applied. In order to calculate biogas production of co-digestion of substrates, a linear relationship between the amount of biogas production and amount of digested substrates is assumed. In other words, the biogas production of the digestion of a combination of substrates is the sum of the biogas production of the digestion of the separate substrates. This assumption is a simplification of reality. For example, if the materials are very different in composition of readily degradable matter this linear relationship might not hold. However, if the retention time of the material in the digester is large one might assume that the potential biogas production may be reached. In these cases the assumption of a linear relationship is acceptable.

For this reason, the data entry box for anaerobic digestion has a completely different look in the co-digestion sheets. This box is shown in Figure 3 - 15.

Anaerobic digestion		Quantity of product	
Inflow materials		Yield	
	Weight-% of feed		
Manure	55%		$9.51\ m^3_{\text{Injected green gas}}\ /\ ton_{\text{Manure, input}}$
Maize	10%		$85.46\ m^3_{\text{Injected green gas}}\ /\ ton_{\text{Maize, input}}$
Potato remains	15%		$84.26\ m^3_{\text{Injected green gas}}\ /\ ton_{\text{Potato remains, input}}$
Sugar beet remains	15%		$52.67\ m^3_{\text{Injected green gas}}\ /\ ton_{\text{Sugar beet remains, input}}$
Glycerine	5%		$472.39\ m^3_{\text{Injected green gas}}\ /\ ton_{\text{Glycerine, input}}$
TOTAL	100%		

Figure 3 - 15   Input field for co-digestion

The biogas production can be estimated given a user specified mixture of substrates. In the predefined tool, four co-substrates are included, i.e. maize, glycerine potato remains and sugar beet remains to be co-digested with manure. The user can define the composition of the digester menu by entering the weight percentages of the appropriate substrates.

3.5.4 Transport before conversion

Emissions from transport before conversion include the emissions from transportation of processed feedstock. The data box for transport of feedstock is shown in Figure 3 - 16. This box is the same box described in section 3.5.2.

Transport of wood pellets			Quantity of product	
Outflow materials			Yield	
Transport yield	0.99	ton transported pellets / ton pellets	0.63	ton transported pellets / ton sawdust input
			0.98	MJ transported pellets / MJ sawdust input
Inflow energy			10761.50	MJ transported pellets / ton sawdust input
Truck for dry product (Dies	160	km		
Fuel	Diesel			
Ocean bulk carrier (Fuel o	5,000	km		
Fuel	HFO			

Figure 3 - 16   Input field for transport before conversion

3.5.5 Conversion

The CO2-tool contains three types of energy conversion processes for the production of electricity and/or heat.The data entry boxes for these conversion types are shown in Figure 3 - 17, Figure 3 - 18 and Figure 3 - 19. The most important part of this box is the data about the outflow energy. In these boxes, the user should specify the yield of electricity in MWh per ton input and/or useful heat in GJ per year. Another important input field is the inflow materials where the user should enter the amount of feedstock in tons that is converted in a year. Based on these inputs electrical and/or thermal efficiency of the installation will be calculated and shown in the corresponding grey cells. In order to calculate the Carnot efficiency that is required for the determination of the allocation factor, the user should also specify the absolute temperature T_h in °C of the useful heat at the point of delivery. If no useful heat is produced, this cell should be zero.

Combustion in boiler			Quantity of product	
Outflow materials			Yield	
Output	1.0	ton$_{Converted\ pellets}$ / ton$_{Transproted\ pellets}$	0.63	ton$_{Converted\ pellets}$ / ton$_{Sawdust,\ input}$
			0.98	MJ$_{Converted\ pellets}$ / MJ$_{Sawdust,\ input}$
Outflow energy			10761.50	MJ$_{Converted\ pellets}$ / ton$_{Sawdust,\ input}$
Useful heat	28800.0	GJ$_{Heat}$ / year		
Temperature, T_h	90	°C		
Thermal efficiency, η_h	90.0%			
Inflow materials				
Input	1859.5	ton$_{Transported\ pellets}$ / year		
Inflow energy				
Natural gas (4000 km, EU I	0.0	MJ / ton$_{Transported\ pellets}$		
Electricity EU mix LV	0.0	kWh / ton$_{Transported\ pellets}$		
Emissions				
CO2	0.0	kg / ton$_{Transported\ pellets}$		
CH4	0.00	kg / ton$_{Transported\ pellets}$		
N2O	0.00	kg / ton$_{Transported\ pellets}$		

Figure 3 - 17   Input field for conversion (combustion in boiler)

Combustion in CHP		Quantity of product	
Outflow materials		**Yield**	
Output	1.0 ton$_{Converted\ pellets}$ / ton$_{Transproted\ pellets}$	0.73 ton$_{Converted\ pellets}$ / ton$_{Sawdust,\ input}$	
		0.98 MJ$_{Converted\ pellets}$ / MJ$_{Sawdust,\ input}$	
Outflow energy		12555.08 MJ$_{Converted\ pellets}$ / ton$_{Sawdust,\ input}$	
Electricity	32000 MWh$_{Electricity}$ / year		
Useful heat	86000 GJ$_{Heat}$ / year		
Temperature, T$_h$	90 °C		
Electrical efficiency, η$_{el}$	26.8%		
Thermal efficiency, η$_h$	20.0%		
Inflow materials			
Input	25000.0 ton$_{Transported\ pellets}$ / year		
Inflow energy			
Natural gas (4000 km, EU	0.0 MJ / ton$_{Transported\ pellets}$		
Electricity EU mix LV	0.0 kWh / ton$_{Transported\ pellets}$		
Emissions			
CO2	0.0 kg / ton$_{Transported\ pellets}$		
CH4	0.00 kg / ton$_{Transported\ pellets}$		
N2O	0.00 kg / ton$_{Transported\ pellets}$		

Figure 3 - 18   Input field for conversion (combustion in CHP)

Cofiring in coal plant		Quantity of product	
Outflow materials		**Yield**	
Output	1.0 ton$_{Converted\ pellets}$ / ton$_{Transproted\ pellets}$	0.63 ton$_{Converted\ pellets}$ / ton$_{Sawdust,\ input}$	
		0.98 MJ$_{Converted\ pellets}$ / MJ$_{Sawdust,\ input}$	
Outflow energy		10761.50 MJ$_{Converted\ pellets}$ / ton$_{Sawdust,\ input}$	
Electricity	32000.0 MWh$_{Electricity}$ / year		
Useful heat	0.0 GJ$_{Heat}$ / year		
Temperature, T$_h$	0 °C		
Electrical efficiency, η$_{el}$	26.8%		
Thermal efficiency, η$_h$	0.0%		
Inflow materials			
Input	25000.0 ton$_{Transported\ pellets}$ / year		
Inflow energy			
Natural gas (4000 km, EU	0.0 MJ / ton$_{Transported\ pellets}$		
Electricity EU mix LV	0.0 kWh / ton$_{Transported\ pellets}$		
Emissions			
CO2	0.0 kg / ton$_{Transported\ pellets}$		
CH4	0.00 kg / ton$_{Transported\ pellets}$		
N2O	0.00 kg / ton$_{Transported\ pellets}$		

Figure 3 - 19   Input field for conversion (co-firing in coal plant)

The user should also enter the energy that is required for the combustion process. This could be natural gas for start-up of the installation, maintaining the temperature or as a backup fuel and electricity for the mechanical operation of the combustion installation.

Note that the carbon dioxide released from the combustion of woody biomass is part of the global cycle of biogenic carbon and does not increase the amount of carbon in circulation. According to Annex I of the EU Communication, the greenhouse gas

emitted during the combustion of solid and gaseous biomass should be taken zero. The methane slip is taken into account.

3.5.6 Processing after conversion

This phase includes the emissions of greenhouse gases due to biogas upgrade into green gas and compression and injection of the produced green gas into the natural gas grid. The data entry box for the biogas upgrade is shown in Figure 3 - 20.

Biogas upgrade		Quantity of product	
Outflow materials		Yield	
Green gas yield	0.619 m3 green gas / m3 biogas	12.99 m3 green gas / ton manure input	
		0.51 MJ green gas / MJ manure input	
Inflow energy		405.92 MJ green gas / ton manure input	
Natural gas (4000 km, EU	0.0 MJ / m3 biogas		
Electricity EU mix LV	0.19 kWh / m3 biogas		
Emissions			
CH4	0.0039 kg / m3 biogas		

Figure 3 - 20   Input field for processing after conversion (biogas upgrade)

In this box, the user should specify the green gas yield in m^3 per m^3 biogas, the amount of electricity and possibly heat that is required for the upgrading process in kWh per m^3 biogas and MJ per m^3 biogas and the emissions due to methane leakage in the biogas upgrading installation.

Figure 3 - 21 shows the data entry box for the compression and injection process.

Compression & injection		Quantity of product	
Outflow materials		Yield	
Injected green gas yield	1.0 m3 injected green gas / m3 green gas	12.99 m3 injected green gas / ton manure input	
		0.51 MJ injected green gas / MJ manure input	
Inflow energy		405.92 MJ injected green gas / ton manure input	
Electricity EU mix LV	0.13 kWh / m3 green gas		

Figure 3 - 21   Input field for processing after conversion (compression & injection)

The yield of injected green gas in m^3 green gas per m^3 green gas should be specified in the upper cell. The electricity requirement for the compression of green gas should be entered in the lower cell in kWh per m^3 green gas. Note that the emissions due to the transport of compressed green gas are neglected in the tool.

3.6 Other fields

The remaining fields are given in Figure 3 - 22. Improved agricultural management, CO2 capture and replacement and CO2 capture and geological storage blocks consist of a single input field for GHG emission savings. The block for land use change (LUC) consists of a drop-down box where the user can indicate if LUC occurs with 'yes' or 'no'. When 'yes' is selected, the user should click on the hyperlink 'sheet LUC' just below the drop-down box and fill in the LUC sheet. After filling in this sheet, the user

can return to the sheet of the current pathway. The resulting carbon stock change (calculated in the LUC sheet) in ton CO2 per hectare is now used in the LUC block of the current pathway.

Land use change, including bonus for production on non-agriculture or degraded land						
e_l	Land use change					
Does LUC occur?	Yes	From : Warm temperature moist ; Native forest (>30% canopy cover) ; Oceanic forest ; Europe ; High activity clay ; No till ; No input				
	Go to sheet 'LUC' to calculate the land use change	To : Warm temperature moist ; Cultivated/cropland ; - ; - ; High activity clay ; Full-tillage ; High without manure				
			per MJ converted biogas			
			g CO$_2$	g CH$_4$	g N$_2$O	g CO$_{2, eq}$
Resulting land use change	19,16 ton CO$_2$ / ha		156,74	0,00	0,00	156,74
Bonus (eB)	0 g CO$_{2,eq}$ / MJ$_{Converted\ biogas}$		0,00	0,00	0,00	0,00
			Result		g CO$_{2,eq}$	156,74

Improved agricultural management				
e_{sca}			per MJ converted biogas	
	0 g CO$_{2,eq}$ / MJ$_{Converted\ biogas}$			0,00
			Result	g CO$_{2,eq}$	0,00

CO$_2$ capture and replacement				
e_{ccr}			per MJ converted biogas	
	0 g CO$_{2,eq}$ / MJ$_{Converted\ biogas}$			0,00
			Result	g CO$_{2,eq}$	0,00

CO$_2$ capture and geological storage				
e_{ccs}			per MJ converted biogas	
	0 g CO$_{2,eq}$ / MJ$_{Converted\ biogas}$			0,00
			Result	g CO$_{2,eq}$	0,00

Figure 3 - 22   LUC, agricultural management, and CCS

3.7 Total results

The total results of the emission calculations are shown in the lowest box in the tool, shown in Figure 3 - 23.

Quantity of product		
Yield	0.63 ton$_{Converted\ pellets}$ / ton$_{Sawdust,\ input}$	
Yield	10761.50 MJ$_{Converted\ pellets}$ / ton$_{Sawdust,\ input}$	
Total emission without allocation:	g CO$_{2,eq}$ / MJ$_{Converted\ pellets}$	8.38
Total emission with allocation adjusted to electrical efficiency:	g CO$_{2,eq}$ / MJ$_{Converted\ pellets}$	31.29
Total emission with allocation adjusted to thermal efficiency:	g CO$_{2,eq}$ / MJ$_{Converted\ pellets}$	0.00
Overall GHG emission reduction		84.2%

Figure 3 - 23   Total results

In the grey area, the total results in terms of quantity of the converted feedstock are shown. The final yield values are expressed in:
- ton converted feedstock / ton feedstock input
- MJ converted feedstock / ton feedstock input

The green area contains the calculation result of the total emission without allocation, the total emission with allocation adjusted to efficiencies and the overall GHG emission reduction.

4 Adapting parameters and pathways

The CO2-tool was created in spreadsheet programme Excel and contains no macro's, Visual Basic code or Wizards. Therfore there are no warnings for out of range inputs and most cells are not protected. As a consequence, the tool is only suitable for users with a basic understanding of greenhouse calculations. On the other hand, the simple structure and the lack of macro's makes the tool transparent and easy to adapt. For adding parameters or steps in a pathway, only a basic understanding of spreadsheets is required. Below we describe how a pathway can be changed.

Changing a parameter

All parameters with a white background can be changed by simple overwriting the current value.

Adding a new parameter

A new input parameter can be added by inserting a new row. For example, when in the Wood pellet – boiler pathway, in the box Pelletization also diesel is used:

- Select row 35 (the one with Natural gas)
- Choose: Insert → rows
- In column A from the new row, type: Diesel (note that this should be in the list of parameter on the tab 'Standard values')
- Type the unit in column C. This is always in MJ / output of the current step (except for electricity where kWh's are used instead of MJ's)
- Type the value in column B
- Copy the formulas from cells I36 through N36 one row up

Warnings:
- When the parameter in column B is not in the list of the tab 'Standard values', Excel will show an error message
- Please note that all fuels are in MJ except for electricity; this is in kWh. This is converted to MJ's in the formula's in columns I, J and K. In the abovementioned example, copying the formulas from row 34 down instead of from 36 up, would have had resulted in an incorrect equation

Adding a new step in a pathway

A new step can be added by copying an excising step. One should be cautious for the same issues as mentioned at 'Adding a new parameter'. In addition to that, it is necessary to complete the summation with the final value of the new box. For example: in the Wood pellet – boiler pathway, the summation is in cell M103 (Total emissions without allocation). This summation should be completed with the sum of the new box (bottom cell in column N of the new box).
Appendix A gives an elaborate example of adding a step. One should understand that adding a step requires an in-depth understanding of the calculation sheets.

Appendix A   Example of adding a new step

In this appendix we explain how to add a step in a pathway by an illustrated example. We take the pathway of wood pellets in a CHP where we add a transport step (100 km by truck) between the collection of sawdust and pelletization. This can be a real case situation when sawdust from small sawmills are collected to a large centralized pellet plant.

We tried to limit the reference to row numbers in the text below since these easily change when a sheet is adapted.

1. Copy an existing transport step and paste this at the right place in the sheet.

Starting at row 39, a transport step is already in the sheet. Therefore we copy rows 39 – 48 (by selecting the entire rows and then Ctrl + c). Next, select row 27 and insert the copied cells. The top part of the pathway looks now as follows (new step indicated):

2. Change names and parameters

Next we change the titles and values:

- Title: Tranport of wood pellets → Transport of sawdust
- Transport yield: 0.99 → 0.98 (we assume 2% of the material is lost during transport)
- Unit of yield: $ton_{Transported\ pellets}$ / $ton_{Pellets}$ → $ton_{Transported\ sawdust}$ / $ton_{Sawdust}$
- Truck for dry product (Diesel): 160 km → 100 km

- Ocean bulk carrier (Fuel oil): 5.000 km → 0 km

This results in:

Transport of sawdust		
Outflow materials		
Transport yield	**0,98**	$\text{ton}_{\text{Transported sawdust}}$ / $\text{ton}_{\text{Sawdust}}$
Inflow energy		
Truck for dry product (Diesel	**100**	km
Fuel	**Diesel**	
Ocean bulk carrier (Fuel oil)	**-**	km
Fuel	**HFO**	

3. Change the block "Quantity of product"

- Change the 3 formulas in the block according the original block. *Note that the moisture content is 30% instead of the 6% of the pellets in the original formula*.
  - Change the units accordingly

This block looks now:

Quantity of product
Yield
0,98 $\text{ton}_{\text{Transported sawdust}}$ / $\text{ton}_{\text{Sawdust, input}}$
0,98 $\text{MJ}_{\text{Transported sawdust}}$ / $\text{MJ}_{\text{Sawdust, input}}$
12553,80 $\text{MJ}_{\text{Transported sawdust}}$ / $\text{ton}_{\text{Sawdust, input}}$

Some formulas must be updated due to the absolute references in the formulas (with $ signs) in the copied cells. One should replace the references to 'old range' cells to the corresponding cells in the 'new range'.

4. Check the block "Calculated emissions"

Most formulas in the columns I, J, K, L and M are copied correctly because of the relative cell references in the formulas. However, this should be checked.

5. Adapt the summation formulas

From the copied cells, only the summations in the bottom cell of the most right column has to be linked to other cells:

- Change cell "Total emission without allocation" (in column M) by adding the total emissions of the new block to the summation.
- Change cell "Yield" (column E) by adding the yield of the new step in the product.

The two cells are indicated here:

Total result		Quantity of product			
	Yield	0,72 t	Converted pellets / ton Sawdust, input		
	Yield	123... MJ	Converted pellets / ton Sawdust, input		
	Total emission without allocation:		g CO₂,eq / MJ Converted pellets		8,61
	Total emission with allocation adjusted to electrical efficiency:		g CO₂,eq / MJ Converted pellets		21,01
	Total emission with allocation adjusted to thermal efficiency:		g CO₂,eq / MJ Converted pellets		7,45
	Overall GHG emission reduction				90,2%

6. Completing the block "Overview results"

- Add an empty row under the row with "Transport of wood pellets"
- In column A: "Tranport of sawdust"
- In column B: make a reference (is equal to) to the total cell of the block (column M, bottom row of the 'new block'.
- In the new row: copy columns C – F from the row above

The top part of the sheet looks now:

Electricity and heat from wood pellets by combustion in CHP — Version 1.0

Overview Results

All results in g CO₂,eq / MJ Converted pellets	Non- allocated results	Product electricity		Product heat	
		Allocation factor	Allocated results	Allocation factor	Allocated results
Cultivation e_ec					
Collection of sawdust	0,0	61,9%	0,0	38,1%	0,0
Processing e_p					
Pelletization	2,1	61,9%	1,3	38,1%	0,8
Combustion in CHP	0,0	61,9%	0,0	38,1%	0,0
Transport e_td					
Transport of wood pellets	5,9	61,9%	3,6	38,1%	2,2
Transport of sawdust	0,6	61,9%	0,4	38,1%	0,2
Land use change e_l	0,0	61,9%	0,0	38,1%	0,0
e_sca + e_ccr + e_ccs	0,0	61,9%	0,0	38,1%	0,0
Totals	**8,6**		**5,3**		**3,3**

Allocation factors
Combustion in CHP
61,9% to electricity
38,1% to heat

Conversion efficiency
Combustion in CHP
25,4% to electricity
44,0% to heat

Emission reduction
Fossil fuel comparator
87   g CO₂,eq / MJ Heat
198   g CO₂,eq / MJ Electricity
GHG emission reduction
91% for heat
89% for electricity
Overall GHG emission reduction
90%

The final emission reduction has reduced from 91% to 90% due to the transport step.